Large Population studies of Globular Clusters from Wide-Field Observations

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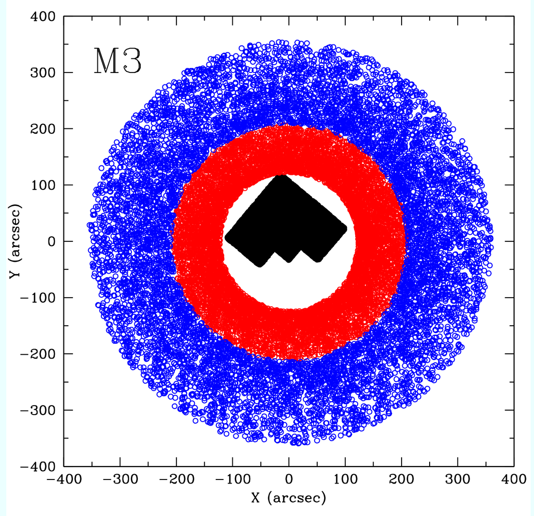
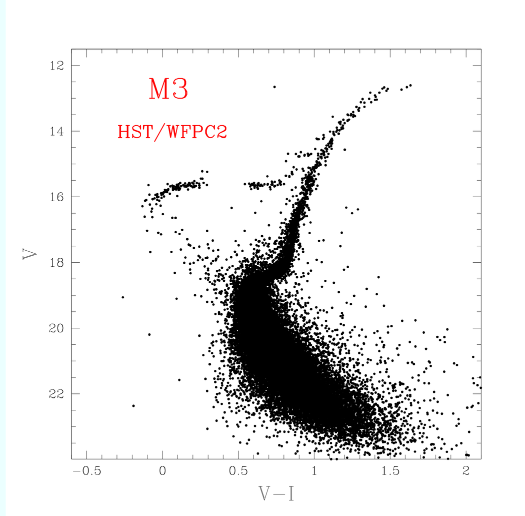
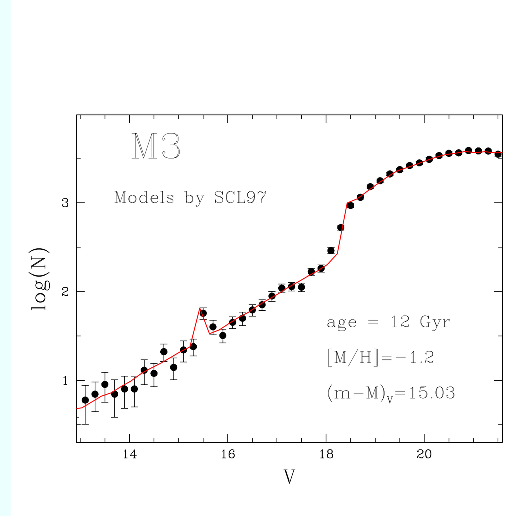
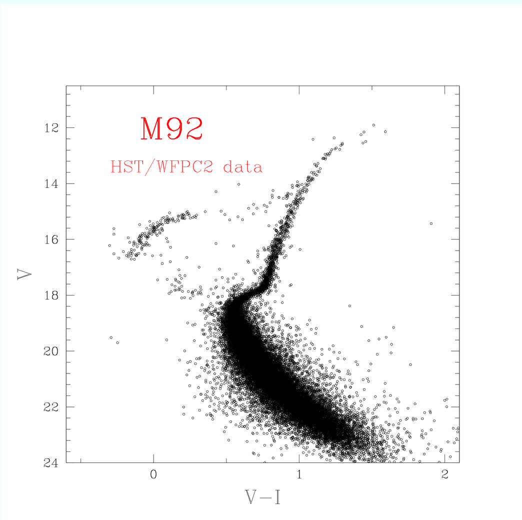
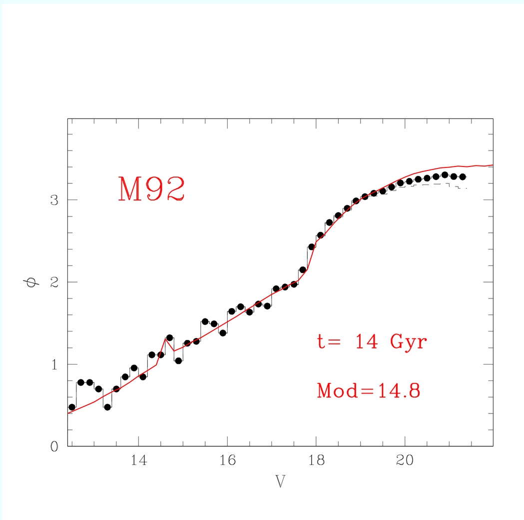
ABSTRACT: Globular star clusters are important astrophysical objects since (1) they are prime laboratories for testing stellar evolution; (2) they are "fossils" of the Galaxy formation epoch, and thus important cosmological tools; (3) they are the largest aggregates in which all post Main Sequence (MS) stars can be individually observed, and thus serve as fiducial templates for all the studies of the integrated light from distant stellar systems. Complete surveys covering the full cluster radial extent also provides important constraints to dynamical models. In this contribution we show a flower of results that we obtained from the combined (space + ground) use of wide-field imaging for a sample of Globular Clusters.











A NEW GENERATION OF CMDs AND LFs: A few years ago, we started an ambitious project aimed to a new global approach to the test of theoretical sequences: the immediate objective of this project was the construction of a *new generation of Color Magnitude Diagrams (CMDs) and Luminosity Functions (LFs)* based on multi–band (from the near–IR to the far UV) observations for selected Galactic globular clusters (GGCs), in which *all post–MS stars at all radii* have been measured.

The validity of this approach has been shown by our work on M3. For this intermediate-metallicity cluster we have constructed (using photographic and CCD ground-based photometry, and HST data) one of the most complete CMD ever obtained for a GGC, covering the entire cluster from the very center to a radial distance of about 6 arcmin [Ferraro et al. (1993, AJ, 106, 2324), Buonanno et al. (1994, A&A, 290, 69), Ferraro et al. (1997, A&A 320, 757), Ferraro et al. (1997, A&A, 324, 915)]. The global LF for the RGB-SGB-MS region is showed above [Rood et al. (1999, ApJ, 523, 752)]: this is still one of the most populated LF ever published for a GGC. As can be seen from the figure above, the comparison with canonical theoretical models (Straniero, Chieffi & Limongi, 1997) show a very nice agreement. Indeed the fit is essentially perfect even in reproducing the location of the RGB-Bump. Similar data have been also secured for other clusters with different structural parameters and metallicity (M92, 47 Tuc, NGC6752 etc- see figures) by using a proper combination of high resolution WFPC2/ACS HST and Wide Field ground-based imaging (the Wide Fiedl Imager (WFI) at the European Southern Observatory - ESO).

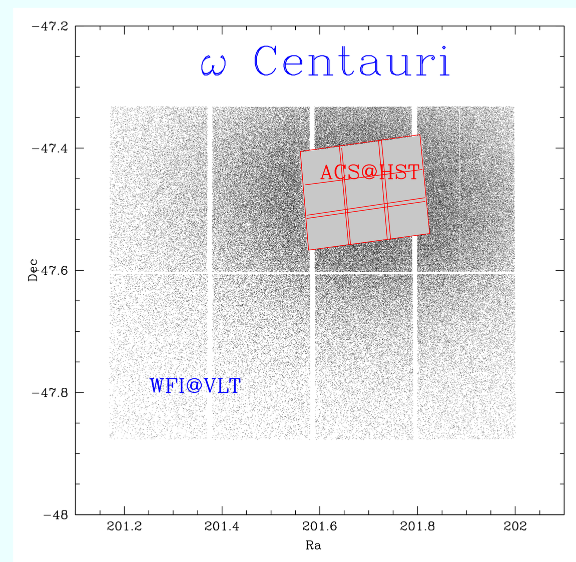
The potential use of such a data-base is huge: in principle any evolutionary phase can be studied over the entire cluster extention allowing *(i)* a high-resolution analysis of the "fine structure" of each sequence and *(ii)* a study of its behaviour as a function of the distance from the cluster center. Here, we show a few results that we obtained in the framework of (1) the study of stellar population in the complex stellar system ω Centauri and (2) the radial distribution of the so-called Blue Stragglers Stars (BSS).

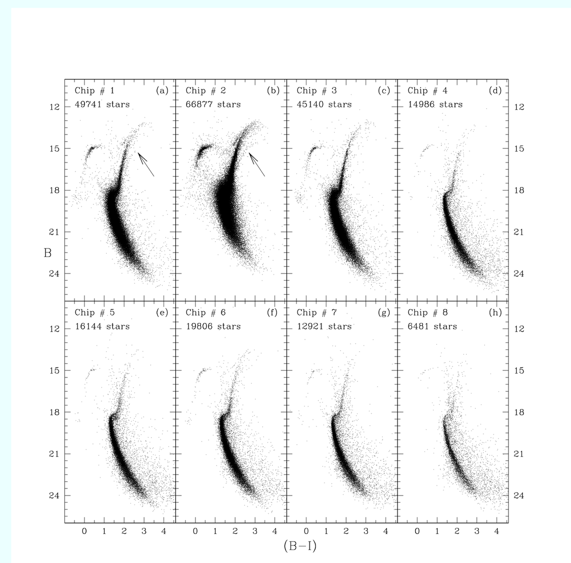
DISCOVERY OF ANOMALOUS BRANCHES IN THE CMD OF OMEGA CENTAURI:

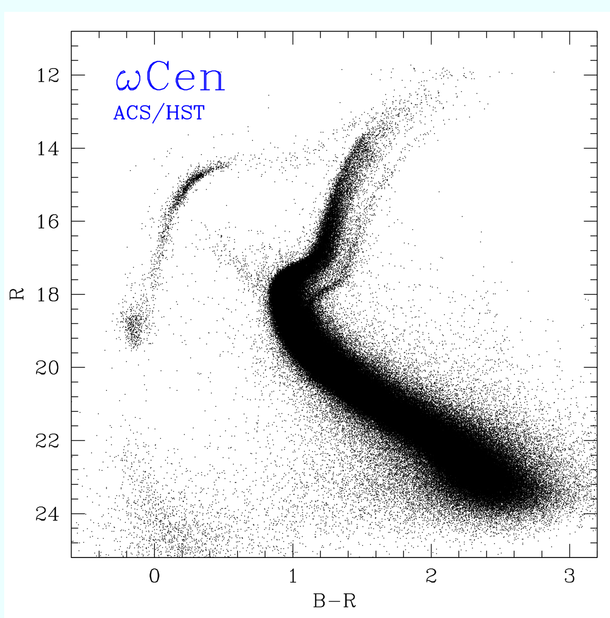
The giant globular cluster ω Cen represents a cornerstone in our understanding of the formation, chemical enrichment and dynamical evolution of stellar systems. It is the most luminous and massive ($5 \times 10^6 M_\odot$, Meylan et al. 1995, A&A 303, 761) GGC and surely the most peculiar one in terms of structure, kinematics and stellar contents. Its most astonishing characteristic is the chemical inhomogeneity: ω Cen is, in fact, the only GGC which shows clear metallicity spread (Norris et al. 1996, ApJ 462, 241; Smith et al. 2000, AJ 119, 1239). From this point of view, ω Cen can be considered a "bridge" system between the GGC, which are unable to retain the gas ejected by their former massive stars, and dwarf galaxies, which are the least massive self-enriching stellar systems known. Because of this, ω Cen has been extensively studied in the past, nevertheless the mistery on the formation and evolution of this system has increased with time. In particular, recent wide-field and high-resolution photometric studies have shown the presence of a number of *anomalous sequences* in its CMDs:

The first surprise: the discovery of the RGB-a - Lee et al. (1999, Nature, 402, 55) and our WFI observations (Pancino et al., 2000, ApJ, 534, L83) have shown the presence of a previously unknown anomalous Red Giant Branch (RGB-a) clearly separated from the bulk of the RGB population (see Figure). By using both optical high resolution spectroscopy and low-resolution infrared spectroscopy we showed that RGB-a stars represent the extreme metal-rich end of ω Cen metallicity distribution, having [Fe/H]~ -0.6 and that they show a lower α-enhancement with respect to the dominant population (Pancino et al. 2002 ApJL, 568, L101, Origlia et al 2003, ApJ, 591, 916) Moreover, we have found that RGB-a stars have a coherent bulk motion with respect to the other clusters stars (Ferraro, Bellazzini & Pancino, 2002, ApJ, 573, L95): this evidence might indicate that RGB-a originated in an independent stellar system probably accreated by the main body of the cluster.

Another piece of the puzzle: the discovery of the SGB-a - By using deep, high resolution multi-band photometry in the central region of the cluster (obtained with FORS1@ESO-VLT and ACS@HST) we recently discovered an anomalous Sub Giant Branch (SGB-a, Ferraro et al 2004 ApJ, 603, L81). This feature appears as a narrow, well-defined Sub Giant Branch (SGB-a), which merges into the Main Sequence of the dominant cluster population at a magnitude significantly fainter than the cluster Turn-Off (TO). The figure above displays the $(R, B-R)$ CMD obtained from the HST/ACS sample.



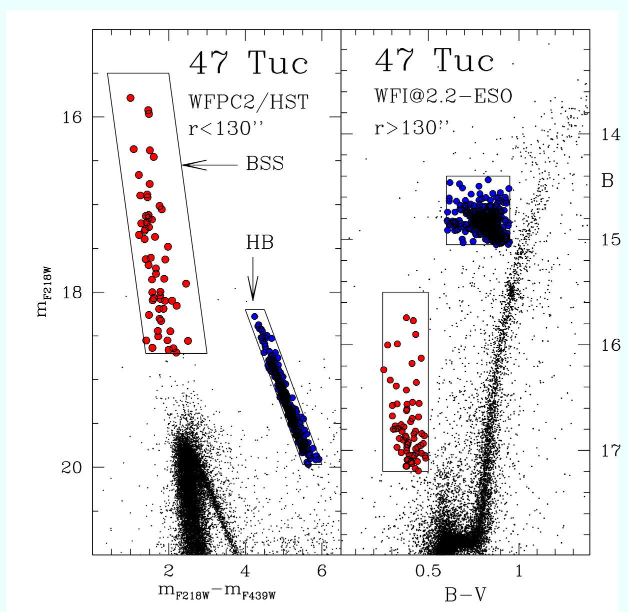


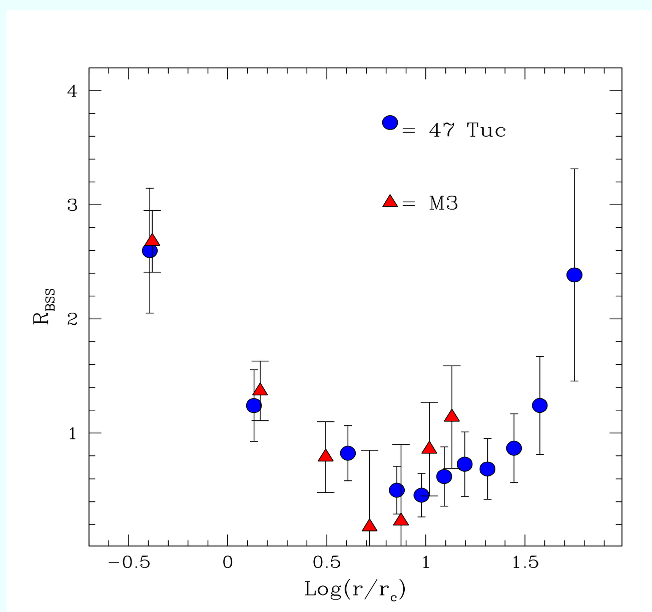


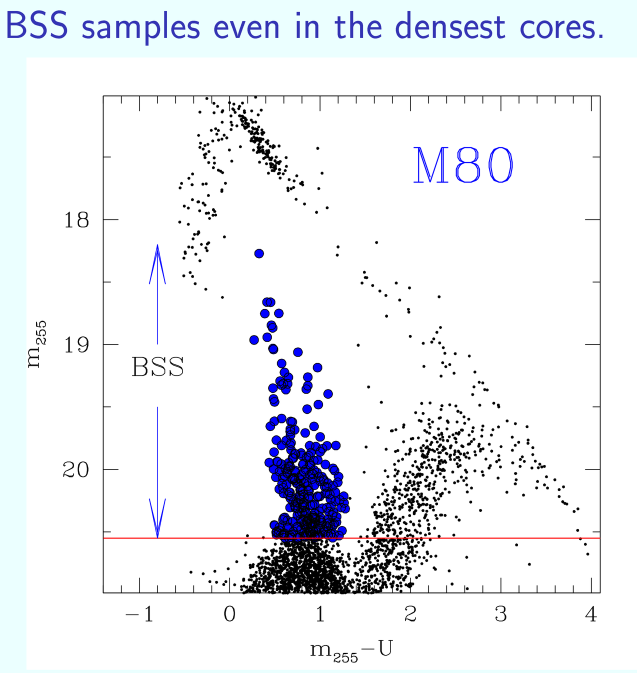
The simplest hypothesis assumes that the SGB-a is the extension of the RGB-a. However, under this assumption its interpretation does not easily fit into the context of a self-enrichment scenario within ω Cen. In fact, its TO magnitude, shape and extension are not compatible with a young, metal-rich population, as required by the self-enrichment process. The TO level of the SGB-a suggests indeed an age as old as the main cluster population, further supporting the extra-cluster origin of the most metal rich stars, as suggested by Ferraro, Bellazzini & Pancino (2002). Only accurate measurements of radial velocities for a representative sample of stars will firmly establish the connection between the SGB-a and the RGB-a and will finally shed light on the origin of the metal rich population of ω Cen.

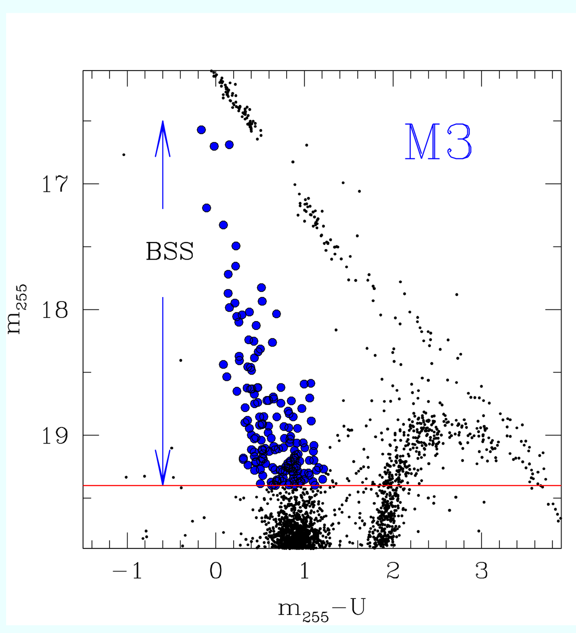
PECULIAR RADIAL DISTRIBUTION OF BSS: TRACING THE DYNAMICAL CLUSTER EVOLUTION :

Blue straggler stars (BSS) appear as a sparsely populated extension of the main sequence above the turnoff point mimicking a rejuvenated stellar population. Since these objects are thought to result from the evolution of various kinds of binary systems whose nature and even existence can be affected by the cluster dynamics, they are considered important tracers of the cluster evolution. The availability of Wide field imaging on board of HST allowed for the first time to search dense cluster cores for BSS. HST offered the further advantage that searches could be conducted in the ultraviolet (UV). In fact, one of the main problem in BSS studies has been the photometric blends which mimic BSS in visible CMDs. While BSS are not especially bright in the UV, the red giants are faint in the UV so that blends are not a problem. In the best UV CMD planes it is possible to obtain complete BSS samples even in the densest cores.









In particular, by combining HST-UV and extensive wide field ground-based observations it is possible to follow the radial distribution of BSS over the entire cluster extention. We are appling this observational strategy to a number of clusters (see figures). On the basis of this data set we discovered that the radial distribution of BSS in M3 is bimodal (highly peaked in the cluster center, rapidly decreasing at intermediate radii, and finally rising again at larger radii, Ferraro et al. 1997, A&A, 342, 915). While this bimodality has been considered for years to be *peculiar*, our latest results show similar bimodal radial distribution in 47 Tuc (Ferraro et al 2004, ApJ, 603, 127, see the comparison of the specific BSS frequency in 47 Tuc and M3 in the figure). This result suggest that the *peculiar* radial distribution first found in M3 is much more *common* that was thought. *It could be the "natural" BSS radial distribution.* Possibly in a few years we will refer to the radial distribution shown in Figure as the typical radial BSS distribution in stellar aggregates. In light of these findings in Mapelli et al (2004, ApJ, 605, L29) we explored the evolution of BSS mimicking their dynamics in a multimass King model for 47 Tucanae. We find that the observed spatial distribution cannot be explained within a purely collisional scenario in which BSS are generated exclusively in the core through direct mergers. An excellent fit is obtained if we require that a sizable fraction of BSS is generated in the peripheral regions of the cluster inside primordial binaries that evolve in isolation experiencing mass transfer.